Tropical Rainfall Measuring Mission (TRMM) Initial Activation and 14 Day In-Orbit Performance Evaluation Report

February, 1998

Abstract:

The TRMM Observatory was launched at 1997-322-21:27:00 from Tanegashima Space Center (TnSC), Japan, aboard an H-II rocket along with its companion payload, ETS-VII. The launch and early-orbit operations went exceptionally well, and there were no significant problems with any observatory components. The initial instrument check-outs also went extremely well, with no major problems reported. This report contains a subsystem and instrument summary of the launch and early orbit operation of all TRMM components through the first 14 days after launch.

Prepared By: ________________ ________________ ________________
T. Feild/568 R. Gallagher/J&T S. Hynes/Swales
TRMM Systems Engineers

Approved By: ______________________________
R. Welsh/TRMM Instrument Manager

____
A. Harper/TRMM Observatory Manager

____
T. Keating/TRMM Systems Liaison Manager

____
T. Williams/TRMM Deputy Project Manager

____
T. LaVigna/TRMM Project Manager

Table of Contents:

1.0 Overview

This report documents the TRMM observatory activities from Launch through Launch plus 14 days. Section 2 describes the state of the observatory before launch and gives a brief description of the launch activities. Section 3 gives a brief description and timeline of the main activities from launch through launch plus 14 days. A thorough description of the nominal power up time-line and early orbit operations is given in the TRMM Launch and In-Orbit Checkout (L&IOC) Plan, TRMM-490-396.

Section 4 provides more detailed information broken down by subsystem. This information is compiled from the subsystem reports, which can be found in the TRMM library.

Appendix A shows some of the first science images from PR, TMI and LIS.

Appendix B contains a brief summary of all of the in-flight anomalies which were reported during this period.

Appendix C shows the launch configuration of the TRMM observatory. Appendix D and E document the configuration of the TRMM observatory at launch plus 14 days.

Unless noted, all times are in UTC (GMT).

2.0 Pre-Launch

2.1 Launch Dress Rehearsal

A launch Dress Rehearsal was held on 11/16/97. At L-10 minutes, immediately after transition to internal power, numerous event messages were received from the ACS processor. Analysis of playback data, as well as data from the timing GSE, showed that there was an apparent interruption in the receipt of the clock signal for approximately 1.4 seconds. This was the only anomaly during the launch dress rehearsal.

A study was completed which showed that a software fix could be developed which allowed adequate observatory operation and time-tagging of science data without a frequency standard or clock card. Since this software fix could be used to meet our redundancy requirement, the decision was made to launch using the B side Clock Card/Frequency Standard.

2.2 Launch Countdown

After the decision was made to use the B side Clock Card/Frequency Standard, the launch was rescheduled for 97-331-20:40 UTC which was Thanksgiving day, November 27, 3:40 PM EST or November 28, 5:40 AM JST. The TRMM observatory was successfully launched on 97-331-21:27.008, 47 minutes into the 2 hour window. This section details a number of minor problems (none regarding TRMM or ETS-VII) that occurred during launch preparations.

The planned launch time was 331-20:40 and the launch window extended until 331-22:40 (a 2 hour window). The weather forecast was good but guarded. The cloud ceiling was 2.5 to 3 km and falling with a launch criteria of 1.5 km.

The TRMM observatory was powered up for launch beginning at 97-331-09:40 (T-11 hours). All operations regarding the TRMM observatory were nominal from power-up through launch.

At approximately T-6 hours the Ogasawara station encountered a problem. This is one of the downrange “Cmd Destruct” sites and it was launch critical. By T-5 hours the Ogasawara station announced that they were “Go”.

At T-3:50, during the rocket fueling operation, one of the pad valves which should have been open was found to be closed. The valve was opened within about 15 minutes. As a result of this and other delays in the fueling NASDA announced that the launch could be delayed by about 30 minutes, but they later announced that they had made up this time and were again able to meet the initial launch time.

At 331-20:16 (T-24 minutes) NASDA announced that although the fuel sensors only read 98% full, they were unable to load any more fuel. If necessary, a hold would be called at T-15 minutes. At 331-20:19 the problem was resolved and it was announced that the tanks were full despite the gauge reading.

At 331-20:30 (T-10 minutes) the observatory transferred to internal power. At 331-20:32:27 a launch vehicle temperature was found to be out of limits. NASDA announced that they would hold at T-4:30 and advised us to go to external power.

At 331-20:39, after discussion with NASDA, TRMM transitioned to external power. Soon after this transition, NASDA announced that the planned launch time had been changed to 331-21:27.

At 331-20:50 NASDA discovered a ship approaching the launch restricted area. At 331-20:53 the temperature issue was corrected, but the ship was still an issue. At 331-21:07 NASDA announced that the ship was no longer a problem, and that the launch time was still 331-21:27.

At 331-21:00 the TRMM launch crew performed the final Virtual Recorder release. This allowed us to meet our memory requirement without another release even if launch had been delayed until the end of the launch window.

At 331-21:14 ETS-VII transferred to internal power. At 331-21:17 TRMM transferred to internal power. The battery #1 and battery #2 SOC were 99.94%. The launch criteria was 95% SOC on each battery. The ACS separation counter was reset at 331-21:18.

At 331-21:21:30 the Mission Director gave the final 'go' to the Mission Director Representative at Tanegashima Space Center (TnSC) and at 331-21:23:50 (T-00:03:10) the rocket auto sequence started. At 97-331-21:27:00.008 the H-II rocket lifted off with the TRMM and ETS-VII satellites.

Time line summary:

1997-331-09:40	TRMM Observatory power-up began
331-11:30	RCS Isolation Valves #1 to #4 were opened
331-14:00	Problem reported at Ogasawara "Cmd Destruct" site
331-15:12	Problem resolved with Ogasawara site
331-16:50	H-II pad valve found in "closed" state
331-17:07	H-II pad valve was opened
331-19:00	Started L-40:00 hold
331-19:02	Final TRMM timing adjustment completed
331-19:24	Transition to 1k telemetry completed
331-20:00	Exited L-40:00 hold
331-20:16	H-II LOX at 98% and couldn't finish loading
331-20:19	H-II LOX issue resolved
331-20:30	TRMM transferred to internal Power:
331-20:32:27	Launch vehicle temperature anomaly detected
331-20:39	TRMM transferred back to external Power
331-20:50	Ship found in downrange area.
331-20:53	Launch vehicle temperature anomaly corrected
331-21:00:49	Final Virtual Recorder release
331-21:07	Ship problem cleared. "Go" for launch at 331-21:27
331-21:14	ETS-VII transferred to internal power
331-21:17	TRMM transferred to internal power
331-21:18	ACS Separation Counter reset
331-21:24	H-II Auto-sequence started
97-331-21:27:00.008	Launch!

3.0 Launch and Early Orbits

3.1 Launch through Observatory Separation

Launch through TRMM/H-II observatory separation went extremely well. All H-II operations, including solid rocket burn-out and jettison, upper fairing jettison, Main Engine Cut-Off (MECO), 1^{st} stage separation, 2^{nd} stage ignition, 2^{nd} engine cut-off, and TRMM separation were nominal and the tip-off rates were very low.

The upper fairing (TRMM fairing) separated at L+00:03:45. At L+00:04:44 TDRS West began receiving TRMM telemetry. The receipt of telemetry verified successful fairing separation and RTS #32 operation. This RTS (#32) turned on transmitter #1.

At L+00:11:33 a no-operation (noop) command was sent to the Command Ingest (CI) task and the CI command counter incremented, verifying successful receipt of the command and operation of the TRMM command link.

At L+00:14:12 the TRMM observatory separated from the launch vehicle.

Timeline summary:

97-331-21:27:00.008	Launch
331-21:30:34	Fairing Separation
331-21:31:44	TDRS West Acquisition
331-21:33	Noop command sent
331-21:34	Noop command verified
331-21:41:12	TRMM/H-II Separation

3.2 Observatory Separation through Launch plus day 14

A timeline of the major events is given below. These events are described in the subsystem accounts in section 4.

Time line summary:

97-331-21:41:12	Observatory separation
331-21:41:12	Start of sequencer
331-21:42:12	+Y Solar Array pyros fire
331-21:42:13	-Y Solar Array pyros fire
331-21:42:14	HGA pyros fire
331-21:42:20	Electrical Subsystem confirms separation
331-21:42:42	RWAs powered ON

331-21:43	Nominal tip-off rates reported
331-21:44:00	+Y Solar Array is indexed
331-22:27:00	Batteries at 100% SOC
331-22:34:06	Transition to 1k/4k telemetry rate
331-23:17:35	TMI Radiometer pyro fired and Radiometer deployed
331-23:23:26	TMI Antenna pyro fired:
331-23:25:29	TMI powered ON
331-23:49	First AGO pass
332-01:25	Isolation Valve #5 opened
332-04:08:12	Transceivers 1 and 2 set to 1k bps command rate
332-05:05	STDN pass to Madrid (DS66)
332-07:25	STDN pass to Canberra (DS46)
332-13:17:29	Start of ACS Safehold test
332-14:48	End of ACS Safehold test
332-14:52:40	LIS powered ON
332-15:48	RCS Pyrotechnic Isolation Valve pyro fired, opening valve
332-15:56:12	1st HGA Dummy track
332-16:21	Contingency Mode Testing performed
332-17:16	SPSDU-B powered OFF
332-17:23:27	PSIB-B powered OFF
332-20:30	Exited Contingency Mode. Returned to Sun Acquisition Mode
332-20:53:57.95	Received initial LIS science data. First TRMM science data.
332-21:03:06	Entered Earth Acquisition Mode
332-21:16:06	Entered Yaw Acquisition Mode
332-21:25:28	Entered Mission Mode
332-22:12	RF Switch #4 changed from 'Omni' to 'HGA'
332-23:38:00	HGA 1st used for communication
333-14:15:46	Roll thruster 1-shot calibration firings
333-14:35:25	TMI spin up
333-14:39:18	TMI receivers powered ON; Science data collection begins
333-17:58:00	ISP thruster calibration firings
334-12:48:01	VIRS powered ON
334-13:44:17	VIRS commanded to outgas mode
334-15:11:01	ISP thruster calibration firing
334-16:45:51	PR powered ON
335-15:03:01	LBS thruster calibration firing
337-19:35:01	1st descent burn
338-20:07:01	2nd descent burn
339-19:05:01	3rd descent burn
339-20:37:01	4th descent burn
340-18:54:01	5th descent burn
340-20:26:01	6th descent burn
341-17:43:38	7th descent burn
341-19:28:42	8th descent burn
341-19:29:52	Mission orbit reached

341-20:45:45 PR enters observation mode at mission altitude

4.0 Subsystem Overviews

4.1 Attitude Control Subsystem (ACS)

The TRMM ACS subsystem has performed well and successfully acquired the sun and transitioned to mission mode as planned in the launch script. Delta V maneuvers were used to place the TRMM observatory in its correct mission orbit. The TRMM ACS is currently meeting its specification for pointing the TRMM observatory. Some issues were encountered which are discussed briefly in the following sections.

4.1.1 Launch through Sun Acquisition

Upon separation from the H-II, the RWAs were autonomously powered by the observatory sequencer and the observatory transitioned from Standby Mode to Sun Acquisition Mode. Sun Acquisition was nominal. When the observatory entered Sun Acquisition Mode the observatory roll, pitch and yaw errors were -8, -26 and -25 degrees, respectively. The total system momentum was 15 Nms. The H-II tip-off rates, as monitored by the gyros, were -0.02, -0.13 and 0.04 degrees/second for roll, pitch and yaw, respectively. These tip-off rates were well below the H-II specified values (less than the 1-sigma values), and as a result Sun Acquisition occurred very quickly. Four RWAs were used to acquire the sun in less than 10 minutes.

At 331-22:27 the Fault Detection and Correction (FDC) marked the TAM A as static and autonomously switched to TAM B (TRMM Anomaly #3). This occurred because the on-orbit *noise* on both TAMs was *lower* than the static threshold that is used to decide if the TAM data is updating correctly. This static threshold has now been lowered and TAM A is again being used. There was never a problem with TAM operation. The TAM data was just *less* ‘noisy’ than was expected.

4.1.2 ACS Safe-Hold Test

From 332-13:17:29 to 332-14:48 TRMM entered safe-hold during a planned test of the safe-hold mode. During this mode, the observatory is held in an inertially fixed, sun-pointing orbit. All safe-hold operations were nominal.

4.1.3 ACS Contingency Mode

During Sun Acquisition the ACS Contingency Mode was tested. In Contingency mode the ACS uses the DSS and TAM data to estimate observatory attitude and gyro biases using a 'Kalman filter' algorithm. This Kalman filter is used in the event of Earth Sensor degradation. In Sun Acquisition Mode the observatory is held in an inertially fixed, sun-pointing attitude using the CSS and gyros. The Kalman filter output is available, but it is not used for pointing the observatory. Thus the performance of the Kalman filter could be tested without affecting observatory performance.

The test began at orbit noon on 332-16:21. It was tested using DSS and TAM data, and during eclipse when only the TAM data was available. The performance was within specification for all cases. However, when the Kalman filter was reinitialized in eclipse, it did not accept the DSS data when it became available. The algorithm overestimated its accuracy without the DSS data and underestimated the accuracy of the DSS data. Thus it was not as accurate as it could have been if it had used the DSS data. The ACS team will retune the Kalman filter and retest it in Mission Mode. At 332-20:30 TRMM exited Contingency Mode and returned to Sun Acquisition Mode

4.1.4 Earth Acquisition and Yaw Acquisition Modes

At 332-21:03:06 the first Earth Acquisition was performed. The ESA changed from course to fine at 332-21:14:15, and at 332-21:16:06 the observatory entered Yaw Acquisition. At 332-21:25:28 the observatory entered Mission Mode. There were no problems in Earth Acquisition mode or Yaw Acquisition mode.

4.1.5 Mission Mode

Mission Mode performance is currently nominal and within pointing requirements.

Upon first entering Mission Mode, yaw updates of approximately +0.3 degrees from DSS A (done at 6 am) and -0.3 degrees from DSS B (done at 6 PM) were observed (TRMM Anomaly #25). Analysis and data review revealed that this was because the DSS heads had been mounted slightly non-orthogonal to each other. The forward DSS A heads were non-orthogonal by 0.08 degrees, and the aft DSS B heads were non-orthogonal by 0.3 degrees. A software patch could be written to account for non-orthogonal DSS heads. However, since the DSS A was only slightly non-orthogonal, it was decided to have FDF calibrate DSS B and the ESA to DSS A.

On 346-14:33:00 a new FDF-supplied alignment matrix was loaded for DSS B and on 346-19:26:22 new FDF-supplied ESA penetration biases were loaded. Yaw updates improved to ±0.15 degrees worst-case, and this will improve once the final alignment tables are loaded.

Yaw updates were also improved by lowering one of the gains (kyaw) with a table load which reduced overcorrecting of the gyro bias.

While in mission mode, the solar arrays track the sun during daylight but are feathered during eclipse to minimize drag. A pre-dawn criteria is set by the ACS Flight Software which allows the solar arrays to be slewed to the sun position before exiting eclipse. In Mission Mode we noticed that the arrays sometimes did not reach the sun tracking position until 1 minute after sunrise (TRMM anomaly report #20). Since power generation is adequate, no change has been made. If power generation becomes an issue, this condition can easily be changed by updating the table which determines the amount of time spent slewing in daylight at each beta angle.

An attempt was made to update the magnetic field model, but we discovered that the epoch for the magnetic field model could not be changed using a table load (it was hard coded in the software). A code change will be required for this model to be updated.

4.1.6 Thruster Calibration and Delta V performance

The TRMM thrusters were fired a total of 12 times during the first two weeks of the mission. There were one-shot firings of each of the roll thrusters, two ten second firings of the ISP thrusters, one ten second firing of the LBS thrusters, and then eight descent burns using the ISP thrusters.

The roll thruster calibration showed that the roll thrusters have the correct polarity and that the momentum impulses were within the expected values. The ISP calibration burns showed that there is a negative pitch disturbance torque, but no appreciable roll or yaw disturbance torques. As a result, the ISP -Y Pitch thruster is off modulated about 34% of the time. Note: Some -Y pitch disturbance torque is expected on TRMM due to the thruster positions and orientations.

4.1.7 Yaw Maneuver Performance

180 degree yaw maneuvers are periodically performed to keep the -Y side of the observatory in the sun. On 347-13:11:02 TRMM performed its first 180 degree yaw maneuver. The first yaw update after the first yaw maneuver resulted in a -0.4 degree yaw update, so the gyro scale factor has been revised to improve the performance. A full gyro calibration by FDF will not be implemented until after the CERES calibration maneuver in January.

4.2 Power Subsystem

4.2.1 Launch to Mission Mode

At lift off the battery #1 SOC was 98.46% and the battery #2 SOC was 98.47%. The observatory became "power positive" (i.e. charge current began flowing into the batteries) at approximately T+14 minutes. The maximum depth of discharge was approximately 4.3% for each battery. A maximum DOD of 60% was allowed for slow acquisition due to high tip-off rates, or other contingencies, but we were fortunate to have been placed into orbit with low tip-off rates and experienced no deployables or ACS anomalies, so TRMM was quickly able to point the arrays to the sun. TRMM achieved 100% SOC on both batteries before the first eclipse.

During the first eclipse, in our launch configuration TRMM drew slightly under 6.5 A from each battery and the minimum SOC was 92.27% and 92.22% for batteries 1 and 2, respectively.

At launch, battery #1 was at 22.37° C and battery #2 was at 23.16° C. The maximum battery temperatures were 22.40° C and 23.21° C for battery #1 and 2, respectively. Again, we were well below the maximum allowed temperature of 30° C because the arrays were pointed at the sun so quickly. TRMM was in sun acquisition mode for 14 charge/discharge cycles following the first eclipse. For the final orbit in sun acquisition mode, the beta angle was -6°, orbit day was 55 minutes 44 seconds, and orbit night was 36 minutes, 14 seconds.

4.2.2 Mission Mode

Power subsystem performance appears nominal for all observed beta angles. The nominal observatory load is about 850 Watts, versus the 1100 Watt design load. The maximum DOD is about 15%, which is well below the specified maximum of 25% due to the reduced load on the observatory.

The maximum solar array output is difficult to monitor since the voltages and currents are constantly changing in peak power tracking mode and they are not sampled at the same time. The maximum solar array output is approximately 3880 Watts, when normalized to account for temperature. These readings have been consistent since launch, so there is no apparent ongoing degradation, and we have plenty of power margin. A more definitive evaluation of the solar array output will be presented in the 60 day report.

The initial battery charge current at start of orbit day is as high as 46 Amps. This may be high for a 50 Amp-hour battery, but is acceptable.

The essential bus voltage varies from about 32.4 Volts (0.7 volt higher than the batteries) to 27.5 Volts (0.2 Volts lower than the batteries).

Once we were pointed to the sun the battery temperatures began to decline and soon reached their nominal operating range of approximately 6° C to 10° C. The maximum gradient between batteries is about 2.8° C, which is acceptable. We would like to keep the batteries from dropping below 5° C.

At 332-17:23:27 PSIB-B was powered OFF.

4.2.3 Solar Array feathering

The solar arrays track the sun from sunrise to sunset. During eclipse, however, the arrays are “feathered”, which means they are commanded to be parallel to the observatory velocity vector in order to reduce atmospheric drag on the observatory. Early in the mission we noticed that the arrays were often still slewing at orbit dawn. The ACS algorithm to predict dawn was often late by as much as 1 minute. An analysis revealed that this slight additional feathering of the arrays could extend the mission life by up to one month. Since there is substantial power margin, no change was made. We are currently investigating ways to extend solar array feathering to other parts of the orbit in order to increase TRMM mission life.

4.2.4 PSIB Day/Night Knowledge

There were initially several issues regarding the PSIB day/night flag. The PSIB uses three values to determine whether it is day or night: Solar Array Voltage, Solar Array Current, and Solar Array Temperature. If the Solar Array Voltage is above 80 Volts *or* the Solar Array Current is greater than 10 Amps *or* the Solar Array Temperature is above 65° C then it is PSIB orbit ‘day’. If all three of these values are below these limits then it is ‘night’. The same values are used for both ‘day’ and ‘night’ detection, and there is no minimum time for which a value must be above or below a threshold before ‘day’ or ‘night’ is declared.

Initially the Voltage threshold was 45 Volts. Immediately before dawn some light must filter through the atmosphere, and the solar array voltage can climb above 45 Volts without producing appreciable current from the arrays. Since the solar array voltage was over the voltage threshold, this was seen as the start of ‘day’ by the PSIB. Occasionally the voltage then dropped below 45 Volts before the current had reached 10 Amps, changing the PSIB state back to ‘night’. It then set the End of Day State of Charge to the current battery state of charge. Since we were just exiting eclipse, this state of charge was very low, causing the appearance of a dangerously low end of day battery state of charge. It also caused problems with the VIRS instrument, since the FDS uses the PSIB day/night flag to control the transfer of data to the solid state recorders. Setting the PSIB day/night voltage threshold to 80 Volts corrected this problem.

Changes in Solar Array temperature are not immediate. Therefore, the PSIB day/night state does not change to ‘night’ immediately upon entrance into eclipse. Since the batteries begin discharging before the solar array temperature drops below the ‘night’ threshold, the battery end of day state of charge is not 100%, even if the batteries were fully charged at the start of eclipse. Because of this, the end of day battery state of charge is typically 99.6%.

PSIB day/night determination will be discussed in more detail in the TRMM 60 day report.

4.3 Communication Subsystem

TRMM was launched with both receivers ON at the 500 k bps command rate and both transmitters powered OFF. The RF switches were set to “Normal”, “Reverse”, “Omni”, “Omni”.

The TRMM fairing separated at 331-21:30:34. After Observatory separation, the SPSDU fairing signals were used to trigger TSMs 44 & 45, which started RTS #32 which turned ON transmitter #1. Transmitter #1 transmitted through the PA and out the omni antennas in TDRS Data Group 1 Mode 2 (DG1/M2) at 1k bps on both I and Q channels. At 331-21:31:44 TDRS West acquired TRMM telemetry.

Initial communications were nominal. The Eb/No was initially 18 dB for the I channel and 23 dB for the Q channel. This gave us adequate margin to increase the data rate on the Q channel, so at 331-22:34:06, transmitter #1 was commanded to DG1/M1 and transmitted at 1k bps on the I channel and 4k bps on the Q channel. Operations were also nominal at this data rate.

At 331-23:49 Transmitter #2 was used to send telemetry at 1024k bps to the Santiago ground station (AGO). Data was successfully received and commands were successfully transmitted using this link. However, the MOC reported seeing loss of detector lock in the receivers (Anomaly #5). It is possible that the TDRS signal was not turned off and that it caused some interference with the Santiago signal. Another Santiago pass is planned to verify operation of the TRMM observatory in STDN/GN mode.

STDN passes were performed starting at 332-05:05 to Madrid (DS66) and at 332-07:25 to Canberra (DS46).

At 332-04:08:12 both receivers were commanded to the 1k bps command rate. There have been no problems with this command rate.

After performing dummy tracks to verify the ability of the observatory to point the HGA to TDRS, RF switch #4 was changed to “HGA” and transmitter #1 was switched to normal mission mode, DG1/M3 (I = 32k bps, Q = 2M bps). Transmitter #2 has also been tested in GN mode (1M bps) and in TDRS DG1/M1 and 2.

At launch, the receiver center frequencies were measured to be 2076941530 Hz for transponder #1and 2076941140 Hz for transponder #2. At launch plus 14 days, they were measured to be 2076942332 Hz for transponder #1 and 2076941147 Hz for transponder #2

There have been no significant problems communicating with the TRMM observatory, however, there have been instances where the receivers temporarily lost lock. These are being investigated, but they have never resulted in any loss of data or commanding. The transmitter center frequencies are approximately 1k apart, which agrees with the thermal vacuum data. For normal mission mode (DG1/M3) WSGT reported that our Eb/N0 was 24 dB for I and 14 dB for Q, which is well above the 4.5 dB needed to achieve a link error rate of $1x10^{-5}$.

4.4 Deployables Subsystem

The Deployables Subsystem comprises the HGA deployment, SA deployment, HGA pointing and SA drive systems. All of these components have operated nominally since launch - the HGA and SA deployed successfully, the HGA is being used to track TDRS during each contact and the Solar Arrays track the sun during each orbit day.

There have been two limit violations in the deployables subsystem. The ACS B safehold flag correctly reads “disabled”. This was initially wrong in the database and caused a limit violation, but the database has been corrected. The second limit violation was a Yellow High for the current on the line which supplies power to the four GSACE motor drive DC/DC converters. This value was not set to account for the worst case conditions, and it has been raised. Both of these two limit violations were data base problems.

4.4.1 SA and HGA Deployment

Approximately 200 ms after observatory separation the SPSDU detected observatory separation and started the hardware sequencer. 61 seconds after separation the +Y solar array pyros were fired, 62 seconds after separation the -Y solar array pyros were fired and 63 seconds after separation the HGA pyros were fired. All three of these components deployed successfully and the 8Hz ACS gyro data clearly shows all 3 solidly latched in their fully deployed position. Immediately after launch there was a brief concern that the HGA was not fully deployed. While the flight data did not match the data that had been seen in pre-launch *simulations*, it did match all of the pre-launch test data from HGA deployments. Therefore, the concern was ill-founded. The +Y Solar Array (SAPY) deployed in 83 seconds, the -Y Solar Array (SAMY) deployed in 56 seconds, and the HGA deployed in 25 seconds. These times are consistent with deployment times measured on the ground.

After +Y SA deployment the IPSDU TMM sent signals to the GSACE which activated the GSACE sequencer. This sequencer closed the GSACE PSM power relay, closed the +Y SA (SAPY) motor relay and issued a SAPY “Init” command. The solar array then rotated 180 degrees so that it would be correctly pointed to the sun when the ACS went into Sun Acquisition Mode.

4.4.2 HGA Tracking

Starting on day 2, HGA dummy tracks were performed during several TDRS events while telemetry was being monitored through the omni antennas. Four dummy tracks were performed at the times shown:

332-15:56:12 to 332:18:51:56 using TDRS West
332-18:58:24 using TDRS East
332-20:24:31 using TDRS West and
332-22:39:45 using TDRS Spare

The HGA dummy tracks were all nominal. From 332-23:38:00 to 333-00:18:00 the HGA was used to support a 32k/128k pass using TDRS West. The HGA has been used routinely for communications since this time. No problems have occurred during HGA tracking during normal operations or RCS thruster operations. For all thruster operations the HGA tracked TDRS without loss of lock, even though HGA pedestal axis rotational velocities during thruster operations are up to 8 times their rate during normal TDRS tracking.

4.4.3 Solar Array Tracking

The solar arrays were commanded to track the sun when TRMM entered Earth Acquisition Mode. Since this initialization, the solar arrays have routinely tracked the sun during orbit day. During orbit night they are commanded to a ‘feathered’ position which reduces observatory drag and thereby extends the mission life. There have been no problems involving the tracking of the arrays; however, the -Y Solar array drive actuator temperature is as much as 5° C above its predicted value. These temperatures are within the -Y Solar array drive actuator temperature limits, but they are highly dependent on beta angle and the observatory was not in the worst case beta angle during this period. The -Y Solar array drive actuator temperatures will be closely monitored until TRMM has seen all beta angles.

4.5 Reaction Control Subsystem (RCS)

4.5.1 Initial RCS Operations

In preparation for launch, Isolation Valves 1 to 4 were opened at approximately 1997-331-11:30. After launch, isovalve #5 was opened at 332-01:25.

At 332-15:45 the pyrotechnic valve pyro was fired, opening the isolation valve to the high pressure tank. The pressurization of the propellant tanks by the regulator was nominal.

Several of the thruster catalyst bed temperatures were slightly higher than predicted by the TRMM thermal model. The differences between the thermal predictions and on-orbit actuals are due to the assumptions made in the thermal model about the surface propertities. However, the catbeds are designed to operate at extremely high temperatures, and the slight deviation from the model represents no hazard to the observatory.

4.5.2 RCS Thruster firings

On day 333, the roll thrusters were calibrated by sending a single 200 ms pulse to each thruster and then verifying the proper change in momentum. Roll thruster operation was nominal. The firing times for these thrusters were:

332-14:15:46 Thruster #9
332-14:18:14 Thruster #10
332-14:20:00 Thruster #11
332-14:22:56 Thruster #12

At 333-17:58:00, ISP thrusters (#5 through #8) were tested during a 10 second Delta-V calibration firing. The delta-V was successful, but the -Pitch thruster was only on for about 7 seconds. At 334-15:11:00 ISP thrusters were retested with the same result. Initial simulations predicted that all four delta-V thrusters would be commanded on for the entire 10 seconds. For such a short duration burn it was not believed that the disturbances would cause the attitude errors to reach the switching limits. When these switching limits are reached, the ACS automatically off-modulates the appropriate thruster. Slight differences in the assumptions for center of mass, thruster alignment, thruster positions, and thrust levels will cause slight variations in the time required to reach the -pitch switching limit. It should be noted that the center of mass is above the x-y plane, so some net -Pitch torque is expected. All RCS thruster and ACS control performance is within the expected range.

At 335-15:03:00 the LBS thrusters (#1 through #4) were tested during a 10 second Delta-V calibration firing. This operation was successful with no off modulation of any of the thrusters.

Next a 60 second test burn was done on the ISP thrusters to further verify ACS/RCS operation for the remaining descent burns. This was successful, with a 67% duty cycle seen on the -Pitch thruster.

Then seven 1 to 3 minute descent burns were done to lower TRMM from 380 km to its nominal 350 km orbit. These burns were all successful.

Data from the FDF indicates that the thrusters are providing 5% greater thrust than modeled.

4.6 Electrical Subsystem

All electrical subsystem operations have been nominal. The launch sequencer successfully detected observatory separation, fired the solar array and HGA pyros and turned on the reaction wheels. The IPSDU successfully detected +Y Solar Array deployment and initiated the GSACE sequencer. The GSACE sequencer successfully initialized the +Y Solar Array. All the instruments were turned on successfully, and the relay changes to configure for mission mode, including powering OFF SPSDU B, proceeded nominally. The relay states for SPSDU B are documented in Appendix D.

The TMI and RCS pyrovalve pyros were successfully fired using their primary pyros. All pyrotechnic operations have been completed successfully. The redundant TMI and RCS pyrovalve pyros are still live on the observatory, but since the TMI deployment and RCS pyrovalve opening were successfully completed using the primary pyros, there is no reason to ever fire these pyros. (The solar array and HGA pyros are dual bridgewire pyros, and one bridgewire from each pyro, primary and redundant, was activated. Therefore, all solar array and HGA pyros have been detonated.)

4.7 Command and Data Handling (C&DH) Subsystem

As mentioned in section 2.1, there was an anomaly involving the A side clock card/frequency standard during the launch dress rehearsal (PFR 1000-005706). As a result TRMM was launched using the B side clock card/frequency standard. B side clock card/frequency standard performance has been nominal, with a drift of between 0.06 to 0.2 microseconds/hour.

The C&DH subsystem flight performance has been nominal. The uplink card and downlink card are used each pass for commanding and telemetry, respectively, and the spacecraft processor has performed all of its functions without incident.

The 2 giga-bit solid state recorders average about 73 single bit flips per orbit (DR#004) and there was one multiple bit failure during the first 14 days (DR#033). This number of errors is consistent with estimates based on the TRMM radiation environment.

There is approximately one 1773 retry per bus per day. This is also consistent with the TRMM radiation environment.

There was one error (DR#013) on the spacecraft 1773 bus while communicating with the ACS processor. This is currently under investigation. We have seen retries from this RT address, so we know that the redundant 1773 channel on this RT is functioning. The error did not result in any loss of data.

4.8 Flight Data System (FDS)

The FDS is operating nominally with no major problems. The following capabilities were verified during the first 2 weeks of operation:

- 1k and 4k telemetry using the omnis
- 1M telemetry through GSTDN
- 32k/2M telemetry using the HGA
- commandability at 500, 1k and 2k bps
- stored command functionality (ATS and RTS)
- telemetry and statistics monitor functions
- data storage and playback functionality for launch and instrument checkout
- desegmentation of science packets by payload manager

Memory errors and 1773 bus errors were discussed in the C&DH section (4.7).

The FOT was unsuccessful in implementing an ATS jump command due to uplinking an invalid timestamp. This is covered in the FOT section.

The telemetry output (TO) task restarted on several occasions (DR#29 and DR#32). In both cases this was caused by the inability of the TO task to output a single frame. This is a known condition and does not interfere with data collection or data storage operations (See write-up for DR #29 and DR #32).

4.9 Thermal Control Subsystem (TCS)

During the first two weeks of the TRMM mission the TCS operated as designed and all components were kept well within allowable temperature limits. This period did not cover all beta angles, and detailed information on the behavior of the observatory at all beta angles will be included in the 60 day report.

At launch, battery #1 was at 22.37° C and battery #2 was at 23.16° C. The maximum battery temperatures were 22.40° C and 23.21° C for battery #1 and #2, respectively. This was well within the 30° C limit placed on the battery temperatures for initial orbit.

Several of the RCS thruster catalyst bed temperatures were higher than predicted (during non-firing, sunlit conditions), but these components are designed to operate at extremely high temperatures and none exceeded their qualification temperatures.

Because of the launch delay and the desire to not perform a 180 degree yaw within the first few days of the mission, a negative beta angle was seen by the observatory when it was first commanded to the earth acquire attitude. Despite the fact that this placed solar loading on the side of the observatory that normally faced away from the sun, no adverse heating affects were observed.

180 degree and 90 degree yaw maneuvers were performed during this period. For these maneuvers there were no thermal problems experienced.

The only thermal issue at this time is the temperature of the -Y Solar array drive actuator. This is currently several degrees higher than predicted and this may be a concern at higher beta angles. This will be addressed in the 60 day report.

4.10 Precipitation Radar (PR)

From launch through launch plus 14 days, all PR operations were nominal. The PR was launched in safety mode where power is supplied from the PSDU to the PR power supply relay, but the PR power supply relays are open. Only the A side survival heater relays were enabled so that the maximum possible heater current was reduced until we were in a stable orbit. On day 2, one of the PR B side survival heater relays was closed.

On day 4, at 334-16:45:51, the PR was turned ON and initial HK/Science telemetry and command verification was performed. Initial performance was nominal.

At 341-20:45:45, PR entered observation mode in nominal mission orbit. During the first 14 days of the TRMM mission, ‘radiation free’ zones were observed over White Sands and Australia (The White Sands requirement was removed on 1/9/98). The PR is commanded into Standby Mode when passing over these zones so that it does not radiate onto these sensitive areas.

So far all PR operations have been nominal and the PR has begun delivery of science data. The following issues were noted by the FOT, but as noted, they are expected operations:

1. In safety mode, the PR temperature hit its yellow low temperature limit. However, this limit was for Mission mode. The limit has been revised.
2. While in observation mode the PR instrument occasionally showed ‘unlock’ on the surface tracking, but this is expected whenever the PR flies over areas with large variations in altitude, i.e. mountain ranges.

The PR instrument is performing well.

4.11 Visible and InfraRed Scanner (VIRS)

At 334-12:48:01 VIRS was turned on. Then its solar shield door was deployed and the radiative cooler door was commanded to the out-gas position. At 334-13:44:17 VIRS was commanded to out-gas mode. VIRS remained in out-gas mode for the remainder of the first 2 weeks of the mission. The VIRS instrument is operating nominally with no problems reported.

Warning flags are occasionally received from VIRS in telemetry, but they are all warning messages that had been seen before launch. These messages are being monitored.

The VIRS time-tag patch was installed immediately after VIRS was powered on. Since the VIRS scan drive was off, the subseconds for the VIRS telemetry packets was static. The initial power-on value for this subseconds field was all 1's, which represents a number of subseconds greater than one second and is invalid. This fooled the time-tag patch into thinking that the VIRS time anomaly was occurring and the patch then inhibited the update of the seconds portion of the time tag (Anomaly #21). The time-tag patch was then removed and was reinstalled immediately prior to turning on the VIRS scan drive. The VIRS time-tag patch is working as planned.

4.12 Clouds and Earth's Radiant Energy System (CERES)

The CERES instrument has performed well with no anomalies or unexpected behaviors.

CERES was launched with instrument power disabled and survival heater power enabled. On day 6 the instrument was powered on. Within 3 orbits the instrument temperatures were within range to begin operations. During the next week the instrument was operated in both crosstrack and biaxial mode with the detector cover still closed. All motor torque values were nominal and consistent with pre-flight test data.

4.13 Lightning Imaging Sensor (LIS)

LIS was powered ON at 332-14:52:40**.** Initially no science data was received because the observatory was in 1k mode and LIS had not reached its operational temperature. As of 97-332-20:53:57.95 all temperatures were within limits and LIS was transmitting valid science data. LIS was the first TRMM instrument to output valid science data.

On December 5, (orbit day 9) TRMM passed over Cyclone Susan and observed infrequent eyewall lightning, a phenomena observed in some hurricanes when they undergo a change of intensity.

The LIS instrument has performed well and has experienced no problems since launch.

4.14 TRMM Microwave Imager (TMI)

TRMM was launched with TMI powered OFF and with both the Radiometer and the Antenna in the stowed configuration. At 97-331-23:17 the TMI Radiometer pyro was fired and Radiometer deployed nominally in about 90 seconds. The deployment was verified by checking the microswitch status from the ISPDU. At 331-23:23:26 the antenna pyro was fired. At 331-23:25:29 TMI was powered on and the antenna deployment was verified from TMI telemetry.

At 333-14:35:25 we sent the command to spin up the TMI radiometer. At 333-14:39:18 the TMI receivers were commanded on, placing TMI in mission mode and initiating the collection of science data. TMI has remained in mission mode, and preliminary indications are that the science data is of excellent quality and the instrument is operating as expected.

TMI data from Cyclone Susan (December 5, orbit day 9) showed cold 85 GHz Polarization Corrected Temperatures (PCTs), suggestive of ice scattering, associated with the eyewall convection. The receipt and interpretation of science data from this cyclone using multiple instruments was a major milestone for the TRMM project.

4.15 Flight Operations

Since launch, the TRMM observatory has been operated by the TRMM Flight Operations Team (FOT) from the TRMM Mission Operations Center (MOC) located at GSFC in building 32 room C241. TRMM operations have gone very well, with only minor problems. These are explained in more detail in the TRMM 14 day FOT report.

Data Quality:

The received data quality has been very good and the number of retransmissions has been less than we experienced during RF end-to-end tests. There are a few minor problems with unnecessary retransmissions and VC63 data, as summarized below, but these are related to ground processing and not the performance of the observatory.

Spacecraft Clock:

The clock has been accurately maintained by the FOT such that the error is below 400 ms.

Missed passes:

During the first two weeks of operation there were only 2 missed TDRS passes. The two missed passes were consecutive events on 339-21:53 and 339-22:47. They occurred following a delta-V maneuver because WSC did not use an updated ephemeris following the delta-V. There have been no problems with TDRS passes following subsequent delta-V maneuvers.

TDRS Scheduling:

The TDRS event on 344-02:11:00 was not long enough to support downloading of all the TRMM science data. As a result, VIRS data was lost. This occurred because of difficulty in scheduling TDRS passes.

Scheduling TDRS passes was especially difficult during the first 2 weeks of the mission because of the launch delay. A few times, there were schedule gaps of up to 2.5 hours, or 70% of our recorder capacity. Compounding the problem, the MOC did not initially receive planning products for TDRS-171, the TDRS West back-up. We now have the ability to schedule TDRS-171 passes, but TRMM does not always receive TDRS coverage every orbit.

In addition, the FOT has been unable to meet the FDF request to alternate between TDRS West and TDRS East every 3 passes.

ATS Jump command problem:

The ground implementation of the ATS jump command does not correctly calculate the time for the jump. This will be corrected in the next MOC software release since being able to skip steps (i.e. ‘jump’) in an ATS is an important operations capability.

GTAS:

Initially there were some problems with the GTAS system and the subsystem engineers had problems getting timely access to observatory data. This has been resolved and GTAS is now functioning adequately.

VR Retransmissions:

As mentioned, the data quality has been good and there has been a low number of requested retransmissions. However, the majority of the retransmissions appear to be related to ground data flow problems. The MOC reports seeing frames out of sequence, while Pacor does not. Nevertheless, the TRMM observatory is being requested to retransmit the frames in question, resulting in a delay in releasing observatory data and an additional burden on Pacor. It would be preferable to never retransmit data that has already been successfully received by Pacor. The MOC is working this issue.

WSC/Australia Regions:

TRMM has been requested to not allow the PR to radiate over certain zones defined for WSC and Australia. Through day 14 a macro has been used to place PR in stand-by mode whenever it crosses one of these 2 regions. There have been no problems with this activity.

Patch Loads:

Initially, if there was more than one patch load the second patch overwrote the first. The FOT now implements all patch loads to reference previous patch loads.

RAID:

The RAID (Platter 2A) has not worked reliably and the system is currently not redundant. If platter 2B were to fail, science data would be lost. The MOC developers are working on resolving this problem.

4k Mode:

Because the 4k data rate was added late in the mission, the FOT did not have time to develop new configuration codes. Instead, they used the configuration codes for the 1k/1k bps rate and respecified the data rate to 4k bps. During the 4k bps events WSC reported problems achieving frame sync lock. However, the MOC was receiving the data. Since a 4k configuration code did not exist, WSC used a default configuration which did not include Reed-Solomon decoding. As a result, WSC was expecting frames of the wrong size. This problem was fixed with the addition of tracking codes for the 4k mode.

5.0 Summary

The TRMM launch and early orbit operations proceeded extremely well and the TRMM observatory is performing nominally. Some anomalies have occurred, but they are all minor and no hardware failures have occurred. The check-out and calibration phase for the observatory systems and instruments will continue for another 45 days and will be described in the TRMM 60 day report.

Science data is being received from the five instruments and the preliminary indications are that all instruments are performing well. The first science images from the PR, TMI and LIS instruments are shown in appendix A.